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OFFICE OF
AIR AND RADIATION

April 24, 2000

CD-00-04 (LDV)

Subject: Using Single-Roll Dynamometer Road Force Parameters in the Fuel Economy Program

Dear Manufacturer:

Starting with the 2001 model year, the SFTP (Supplemental Federal Test Procedures) regulations require the use of a 48" single-roll electric dynamometer for both emissions and fuel economy testing according to a phase-in schedule. The change to the single-roll dynamometer results in changes to the way road forces are expressed. This letter will discuss how to use these new road force values in the fuel economy program.

Background

The single-roll electric dynamometer is a significant improvement over the current twin-roll hydrokinetic dynamometer. The single-roll equipment can reproduce the actual roadload over an extended speed range (10 to 70 mph), while the twin-roll equipment uses a 'fixed' load vs. speed relationship which is matched only at a single speed (50 mph, based on a 55 to 45 mph coastdown). The large-diameter single roll surface is also a better representation of the actual flat road surface than the pinching action experienced by tires cradled between the two small rollers of the twin-roll dynamometer. The improved tire/dynamometer interface should encourage the design of tires which achieve better fuel economy in actual use.

While all these changes result in better simulation of actual vehicle operation on the dynamometer during our testing, there is a change in terminology that requires our fuel economy grouping policy to be updated. The road forces for testing on a single-roll dynamometer are expressed using the coefficients of a three term force equation (f_0, f_1, f_2; which are the constant, linear, and squared coefficients, respectively, of the combined mechanical and aerodynamic track force equation; expressed in English units) determined using the procedures of SAE J2263 (or equivalent procedures). The road forces on the twin-roll dynamometer, which could be used exclusively prior to the 2001 model year, are expressed as a DPA (Dynamometer Power Absorber) horsepower which is added to duplicate on the dynamometer the 55 to 45 mph coastdown time measured on the track as described in EPA Advisory Circular No. 55c. The track road forces replicated on the twin-roll dynamometer are determined based on a two-term track force equation (f_0 and f_2).

Grouping Vehicles into Subconfigurations for Fuel Economy Calculations

The fuel economy program defines a subconfiguration based on "road-load horsepower" (ref. 40 CFR 600.002-95 (a) (51)). For the twin-roll dynamometer, the Agency had previously interpreted "road-load horsepower" to be the DPA value rounded to a tenth of a horsepower. For the single-roll dynamometer the equivalent parameter is the "Total Road Load Horsepower" at 50 mph ($TRLHP_{50}$), rounded to a tenth of a horsepower. The $TRLHP_{50}$ is the value of horsepower calculated from the track force equation as follows:

For single-roll dynamometers with three-term track force coefficients f_0, f_1, f_2:

$TRLHP_{50} = [f_0 + (f_1 \times (50)) + (f_2 \times (50)^2)] / 7.5$

Round to 0.1 hp

For twin-roll dynamometer with two-term track force coefficients f_0, f_2:

$TRLHP_{50} = [f_0 + (f_2 \times (50)^2)] / 7.5$

Round to 0.1 hp

During the phase-in period, manufacturers will have vehicles testing on both single-roll and twin-roll dynamometers. It is not appropriate to use different methods to express "road load horsepower" in the same fuel economy calculations as vehicles may be improperly grouped based on differences in the calculation procedures rather than based on actual vehicle differences. Consequently, the Agency will require that only one method to be used for all manufacturer fuel economy calculations in a given year. Based on the joint recommendations of the Alliance of Automobile Manufacturers and AIAM, EPA will allow the following procedures to be used during the phase-in period and beyond.

2001 model year

Continue the current practice of using the DPA value as the "road-load horsepower" in the subconfiguration definition for both twin-roll and single-roll dynamometers. Manufacturers would need to develop DPA values in addition to the three-term track road force equation coefficients (f_0, f_1, f_2) for vehicles to be tested on the single-roll dynamometer. As an option, a manufacturer may use the 2002 model year policy for all the vehicles in their fleet starting in the 2001 model year.

2002 and later model years

Use the $TRLHP_{50}$ value (as defined above) as the "road-load horsepower" in the subconfiguration definition for both twin-roll and single-roll dynamometers.

Analytically Derived Fuel Economy (ADFE) Calculations

The regression equations developed for ADFE calculations (ref. EPA Guidance Letter number CD-95-08 (LDV), dated May 12, 1995) were based on a large amount of twin-roll dynamometer testing. The study used differences in DPA and Tire Chassis Loss (TCL) as variables in the regression equations. These parameters are not directly available when conducting testing on a single-roll dynamometer. Furthermore, the single-roll dynamometer could result in different values for the coefficients in the regression equation or for the confidence intervals of the data. So in the long term a new analysis is warranted, however, at the present time there is not a suitable database of single-roll test data on which to base a new analysis.

To allow sufficient time to collect and analyze data, EPA will accept the use of the current equations through the 2004 model year. Starting in the 2005 model year, EPA will only allow an ADFE which is based on an approved regression analysis of single-roll dynamometer test data. Based on the information provided jointly by the Alliance of Automobile Manufacturers and AIAM in their February 18, 2000 letter (copy enclosed), EPA concurs that the best fit is obtained by using three-term coefficients for front wheel drive (FWD) vehicles and the two-term coefficients for real wheel drive (RWD) vehicles. Consequently, through the 2004 model year, manufacturers may continue to use the regression equations presented in EPA guidance letter number CD-95-08 and calculate the TCL and DPA values used in those equations as follows:

For FWD vehicles (use the three-term track force coefficients f_0, f_1, f_2)

$TCL = (f_0 + (f_1 \times 50)) / 7.5$

$DPA = (f_2 \times (50)^2) / 7.5$

For RWD vehicles (use the two-term track force coefficients f_0 and f_2)

$TCL = f_0 / 7.5$

$DPA = (f_2 \times (50)^2) / 7.5$

In some cases a manufacturer may not have two-term track force coefficients available because only the three-term track force coefficients are required to be calculated to run the tests. In such cases, the manufacturer may calculate the two term coefficients using the following equations for data developed from a 60 to 20 mph coastdown. See the joint Alliance and AIAM letter dated February 18, 2000 (enclosed) for the derivation of these equations and for a general solution which may be used for a coastdown over another speed range.

For a coastdown from 60 to 20 mph, calculate two-term track coefficients (f_0 and f_2) from three-term track coefficients (g_0, g_1, g_2) as follows:

$f_0 = g_0 + (18.69\ g_1)$

$f_2 = g_2 + (0.0123\ g_1)$

If you have any questions on this matter, please contact Mr. Eldert Bontekoe at 734-214-4442 or your certification team representative.

Sincerely,

Gregory A. Green

Gregory A. Green, Director
Certification and Compliance Division
Office of Transportation and Air Quality

Enclosure

Alliance of Automobile Manufacturers

AIAM

The World's Leading Automakers®

Mr. Greg Green
Environmental Protection Agency
USEPA National Vehicle and Fuel Emissions Laboratory
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Ann Arbor, MI 48105

Subject: Analytical Derived Fuel Economy (ADFE) Equation and the Phase out of Dual Roll Dynamometers

Dear Mr. Green:

As discussed in our January 17, 2000 letter on Fuel Economy Subconfiguration Determinators, the Alliance of Automobile Manufacturers (Alliance) and Association of International Automobile Manufacturers (AIAM) recommend the following solutions for the phase out of the dual roll dynamometers and the use of the ADFE equation.

1) For all vehicles, maintain the ADFE equation, coefficients, and provisions contained in the May 12, 1995 Dear Manufacturer Letter CD-95-08 (LDV).
2) For data on vehicles tested on dual rolls, maintain the present methods.
3) For data on vehicles tested on single rolls, use roadload coefficients to calculate estimated DPA and tire chassis loss (TCL) terms for use in the EPA ADFE equation.
   - For FWD vehicles, use the three-term roadload coefficients.
   - For RWD vehicles, use the two-term roadload coefficients. The least squares method described in Attachment 1 is proposed as an alternate method to derive two term coefficients from three term coefficients.
4) Start collecting data on single rolls to develop new equations/coefficients for future model years.

The Alliance and AIAM members propose to begin using the recommended changes starting in the 2001 MY.

Justification

In adopting the ADFE policy described in CD-95-08 (LDV), EPA recognized the need and the opportunity to reduce testing burden without affecting label and CAFE integrity. The ADFE sensitivity coefficients were based on analysis of more than 2200 twin roll tests. The use restrictions included in CD-95-08 limit when, how and how many ADFE calculations can be utilized. The practical effect is that most ADFE determinations are used to account for minor product variation within a vehicle line/engine/transmission combination. Mass or roadload variation due to specific model content, optional tires and axles are typical situations suited for ADFE utilization. The sensitivity coefficients for test weight class, N/V, DPA, and TCL do an acceptable job of adjusting fuel economy to account for this product variation.

New ADFE coefficients should be derived based on single roll data generated from current vehicles. Unfortunately, insufficient single roll data exists today to perform the analysis. However, there is no reason to believe that fuel economy sensitivity to small mass and load changes will be substantially different for single roll testing. Accordingly, the current sensitivity coefficients are appropriate for use with single roll testing until a more robust analysis is possible.

The only stumbling block to using the current sensitivity coefficients for single roll testing is that the twin roll DPA and TCL parameters will generally not be available for SFTP compliant vehicles. The industry is proposing a method to derive estimated DPA and TCL values from three term and two term roadload coefficients.

A vehicle's total road load horsepower is a combination of two components, the dynamometer load and the tire chassis losses. Therefore, the track force coefficients can be used to describe each of these two components as follows:

3-term track force coefficients, f_0, f_1, and f_2

$$TRLHP_{50} = (f_0 + f_1(50) + f_2(50^2))/7.5$$
$$TCL = (f_0 + f_1(50))/7.5$$
$$DPA = f_2(50^2)/7.5$$

2- term track coefficients, f_0 and f_2

$$TRLHP_{50} = (f_0 + f_2(50^2))/7.5$$
$$TCL = (f_0)/7.5$$
$$DPA = f_2(50^2)/7.5$$

An analysis of over 700 subconfigurations of Ford cars and trucks and a small sample of GM and DC vehicles showed that the 2-term equation gave comparable DPA and TCL values for rear wheel drive vehicles, and the 3 term equation more closely duplicated the values for front wheel drive vehicles. Attachment 2 demonstrates the typical differences in the parameters for several vehicles and demonstrates that the 2-term coefficient simulates the TCL and DPA better than the 3-term coefficients for RWD vehicles. It is widely recognized that twin roll tire losses for FWD vehicles overstate road tire losses due to the impact of higher drive axle weight and the twin roll geometry. The three term $f_0 + f_1(50)$ value is larger than the two term f_0 value. It is not surprising that the larger value better represents FWD twin roll tire losses and the smaller value better represents RWD twin roll tire losses.

To determine the effect of the proposed use of the track force coefficients, the adjusted fuel economy using the old and proposed method was compared assuming a 1 TCL or 1 DPA increase and decrease. The results below demonstrate that the difference in adjusted fuel economy is, on average, insignificant. The data represent over 700 data points.

	1 DPA Increase	**1 DPA Decrease**	**1 TCL Increas e**	**1 TCL Decrease**
Average Fuel Economy Difference assuming 20.7 mpg for trucks and 27.5 mpg for cars	0.00 mpg	0.00 mpg	-0.01 mpg	0.00 mpg
Standard Deviation	0.04 mpg	0.02 mpg	0.07 mpg	0.05 mpg

Conclusion

The Alliance and AIAM member companies request your approval to apply the provisions of CD-95-08 (LDV) to single roll tests using the proposed DPA and TCL derivation method. Manufacturers are ready to work with EPA to update ADFE coefficients as more single roll data becomes available.

If you have any questions or issues with the above recommendations, please contact Robert Babik, Director, Environmental Programs of the Alliance at 734-658-8005. If you wish, we would be willing to meet with you to discuss this in more detail.

Sincerely,

Robert F Babik

Robert Babik
Director, Environmental Programs
AAM

John Cabaniss

John Cabaniss
Director, Air Quality
AIAM

cc: Dan Harrison
Eldert Bontekoe

Derivation of 2-Term Coastdown Force Coefficients from 3-Term Coefficients

Given 3-term force coefficients (g0, g1 and g2), it is possible to calculate the best 2-term (f0, f2) coefficients by using a least squares integration method over a defined speed (V) range.

The error-squared function between the known "g" curve and the unknown "f" curve at a velocity V is

eq. 1: $$e^2 = \left((f_0 + f_2 V^2) - (g_0 + g_1 V + g_2 V^2)\right)^2$$

Integration over the speed range from initial velocity V_i to final velocity V_f provides the total square error E

eq. 2: $$E = \int_{V_i}^{V_f} e^2 \, dV$$

The best-fit f-terms are solved by differentiating E with respect to f0 and f2, and setting the two equations to zero. This minimizes E, and allows for 2 equations with 2 unknowns.

eq. 3, 4: $$\frac{\partial E}{\partial f_0} = 0, \frac{\partial E}{\partial f_2} = 0$$

In order to reduce the algebra significantly, the integration and differentiation operations on eq2, 3 and 4 are reverse ordered, i.e. eq3,4 may be written as

eq5,6 $$0 = \int_{V_i}^{V_f} \frac{\partial e^2}{\partial f_0} \, dV \;, \quad 0 = \int_{V_i}^{V_f} \frac{\partial e^2}{\partial f_2} \, dV$$

Expanding these...

eq6,7 $$0 = \int_{V_i}^{V_f} 2 \, e \, 1 \, dV \;, \qquad 0 = \int_{V_i}^{V_f} 2 \, e \, V^2 \, dV$$

The integrations become of the form...

eq 8

$$0 = \int_{V_i}^{V_f} \left((f_0 - g_0) - g_1 V + (f_2 - g_2) V^2\right) dV$$

eq 9

$$0 = \int_{V_i}^{V_f} \left((f_0 - g_0) V^2 - g_1 V^3 + (f_2 - g_2) V^4\right) dV$$

Using the following convention to describe the integration limits: $V_n = (V_i^n - V_f^n) / n$

...the solutions to the integrations are:

eq 10 $$(f_0 - g_0) V_1 - g_1 V_2 + (f_2 - g_2) V_3 = 0$$

eq 11 $$(f_0 - g_0) V_3 - g_1 V_4 + (f_2 - g_2) V_5 = 0$$

The solutions to f0, f2 are:

eq 12 $$f_0 = g_0 + g_1 (V_2 V_3 - V_1 V_4) / (V_3^2 - V_1 V_5)$$

eq 13 $$f_2 = f_0 + g_1 (V_3 V_4 - V_2 V_5) / (V_3^2 - V_1 V_5)$$

Over a 60 to 20 mph coastdown range

eq 14 $$f_0 = g_0 + 18.69 g_1$$

eq 15 $$f_2 = g_2 + .0123 g_1$$

Comparison of Actual ADFE Parameters and Calculated ADFE Parameters

Comparison of TRLHP/DPA/TCL (Typical Results for 8 Randomly Selected Vehicles)

Present Vehicle Description										*Calculated Using Road Load Coefficients*					
Vehicle	**Drive**	**ETW**	**CDT**	**TRLHP**	**DPA**	**TCL**	**FO***	**F1***	**F2***	**TRLHP**	**% diff.**	**new TCL**	**% diff.**	**DPA**	**% diff.**
Escort Coupe	FWD	3375	18.83	11.0	5.6	5.5	28.2	0.291	0.017	11.3	-2%	5.7	-4%	5.6	0%
Cougar	FWD	3375	17.82	11.7	5.8	5.9	30.6	0.269	0.018	11.9	-2%	5.9	0%	6.0	-4%
Windstar	FWD	4250	17.09	15.3	8.5	6.8	33.9	0.386	0.026	15.7	2%	7.1	3%	8.6	1%
Dodge Caravan	FWD	4000	16.50	15.0	7.8	7.2	27.1	0.480	0.025	15.1	1%	6.8	-5%	8.3	7%
Crown Victoria	RWD	4250	18.76	14.0	9.5	4.5	33.9		0.029	14.1	1%	4.5	1%	9.6	1%
Explorer 4x2	RWD	4000	16.46	15.0	10.4	4.6	33.9		0.031	15.0	0%	4.5	-2%	10.4	0%
Expedition 4x2	RWD	5250	15.52	20.9	13.1	7.8	57.8		0.041	21.5	3%	7.7	-1%	13.7	5%
Mercedes	RWD	3750	17.55	13.2	6.9	6.3	47.0		0.021	13.2	0%	6.3	0%	6.9	0%

* F0 and F2 calculated based on method found in attachment 1 for RWD vehicles

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Percent Difference between Actual TCL/DPA and Calculated TCL/DPA (Large Sample Size)

	Calculated using 3-term coeff.		Calculated using 2 term coeff.		FWD, 3-term; RWD, 2-term	
	TCL	DPA	TCL	DPA	TCL	DPA
average	44%	-20%	2%	2%	4%	0%
sdev	44%	20%	18%	10%	17%	8%

(n=742 vehicles; made up of 707 RWD and 35 FWD subconfigurations.)